Holographic Quantum Quenches and Anomalous Transport

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Numerical Relativity and Holography.

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In collaboration with

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The questions

Anomalous transport

What is the evolution of the CME when chiral charge is dynamically generated?

Holographic Quenches

How to characterize the initial time behavior of the system?

How does the anomaly affect previous results on holographic quenches?

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Overlooked effect: (almost) stationary currents related to Landau levels

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How to characterize the initial time behavior of the system?

It is possible to DIRECTLY compute the amplitudes of the QNMs. The growth rate might be used as a definition of "initial time"

How does the anomaly affect previous results on holographic quenches?

Universal behavior for fast quenches is found. The relaxation time of the system decreases with the anomaly

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Outlook

1. Anomalous transport
2. Holographic model
3. QNM amplitudes from Laplace
4. Resonances
5. Conclusions

Anomalous transport: "Overview"

Transport phenomena linked to the existence of anomalies in the microscopic theory

- Macroscopic quantum effects
- Interesting non-usual properties
- Test for axial and gravitational anomalies
- Negative magnetoresistance already tested!

The chiral magnetic effect

[Kharzeev et al.]

Generation of an electric current along an external magnetic field in presence of chiral imbalance $\mu_5 \neq 0$.

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- These are strongly coupled $\longrightarrow$ Holography!

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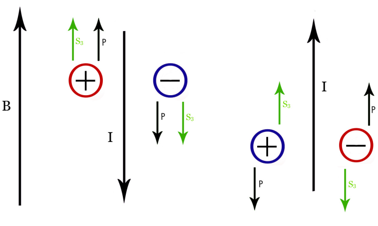

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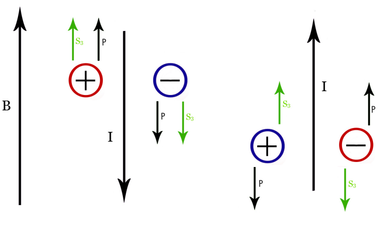

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The bottom-up holographic model

The model consists of two photons A_μ "axial" and V_μ "vector" coupled via Chern-Simons term

$U(1) \times U(1)$ anomalous model

$$\mathcal{L} = \left(-\frac{1}{4}F^2 - \frac{1}{4}H^2 + \frac{\kappa}{2}\epsilon^{\mu\alpha\beta\gamma\delta} A_\mu \left(F_{\alpha\beta}F_{\gamma\delta} + 3H_{\alpha\beta}H_{\gamma\delta} \right) \right)$$

$F \equiv dA, \;\; H \equiv dV$

This C.S. term leaves the vector current conserved

$$\langle \partial_i J^i_V \rangle = 0\,, \qquad \langle \partial_i J^i_A \rangle = \frac{\kappa}{2} \left(F_{ij}F_{kl} + 3H_{ij}H_{kl} \right) \epsilon(\rho ijkl).$$

Probe Limit: Background AdS_5-Schwarzschild (E.F. coordinates)

$$ds^2 = \frac{1}{\rho^2} \left(-f(\rho)dv^2 - 2\,dv d\rho + dx^2 + dy^2 + dz^2 \right) \qquad f(\rho) = 1 - \rho^4\,.$$

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The idea

The anomaly provides us with a mechanism of axial charge generation

$$\partial_\mu J_5^\mu \sim F \wedge F \qquad \longrightarrow \qquad \dot{q}_5 \sim E \cdot B$$

- We consider a static B and a parallel, time dependent E(t).
- The axial charge evolution is the determined by the profile of E

Minimal field content

$$V_x(y) = By \qquad V_z(v,\rho) \sim E(t),\, J_z(v) \qquad A_v(v,\rho) \sim q_5(v)$$

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The equations

Equations in Eddington Finkelstein coordinates

$$A_v'' - \frac{1}{\rho} A_v' - 12\kappa B V_z' \rho = 0\,,$$

$$V_z'' + \left(\frac{f'}{f} - \frac{1}{\rho}\right) V_z' - \frac{2}{f}\dot{V}_z' + \frac{1}{\rho f}\dot{V}_z - 12\kappa B \frac{\rho}{f} A_v' = 0\,,$$

$$\dot{A}_v' - 12\kappa\rho B \dot{V}_z = 0\,.$$

Integrating the constraint and substituting back in the equation for Vz

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Solving the equations

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LET'S NOT DO THAT

Spectral decomposition for Schwarzschild (asymptotically flat)

$$V(v,\rho) = \sum_{n=0}^{\infty} \eta_n e^{\omega_n v} \phi_n(\rho)$$

" it would be clearly desirable [...] to write the solutions of initial value problems associated with linear dissipative wave equations in a given black-hole background-metric as a similar superposition, with the quasi-normal modes being defined as the eigenvalues of an appropriate operator"

- In 1604.02261 [Ansorg & Macedo] show explicitly how to construct this superposition. Amplitudes!
- However, this only provides the entire solution for $v > \tau$ where τ is the mutual growth rate of the amplitudes.
- What happens in AdS?

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QNM amplitudes: how to

Redefine your field(s) to rewrite the equation(s) in terms of the normalizable mode(s)

$$Vz(v,\rho) \longrightarrow V_0(v) + \rho V_1(v) + \rho^2 U(\rho, v) + (Logs)$$

Consider the dynamical equation in the form

$$\alpha[U] + \beta\left[\frac{\partial}{\partial v} U\right] = S$$

$\alpha(\rho)$ and $\beta(\rho)$ are differential operator acting on the radial coordinate ρ
S contains info of the source and its time derivatives.

Laplace transform the equation

$$\alpha[\bar{U}] + s\,\beta[\bar{U}] = \bar{Q} \qquad \bar{Q}(\rho;s) = \bar{S}(\rho;s) + \beta[U_{\rm in}](\rho;s)$$

Where $U_{\rm in}(\rho) = U(\rho,0)$ is the initial data.

QNM: s_n with $\phi_n(\rho)$ is a regular solution to the homogeneous equation

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$\bar{U}(\rho; s)$ has poles on the quasi-normal modes; introduce the decomposition

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At leading order in the $s \to s_n$ limit one finds as regularity condition

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At second order, we obtain

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This equation is to be solved simultaneously for $\bar{W}(\rho)$ and η_n with the normalization condition $\bar{W}(\rho_0) = \bar{W}_0$

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Growth rate

Discrete spectral decomposition is not convergent

$$f(v,\rho) = \sum_{n=0}^{\infty} A_n e^{-i\omega_n v}$$

asymptotically ($n \to \infty$) for Schwarzschild Minkowski [Ansorg, Macedo] and in Schwarzschild AdS [us], it is found that generically

$$|A_n| \sim e^{\tau \mathrm{Im}[\omega_n]}$$

Therefore in principle this solution converges for $v > \tau$

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$$\sum e^{\mathrm{Im}[\omega_n](\tau - v)} e^{-i\mathrm{Re}[\omega_n]v} = \frac{1}{1 - e^{\mathrm{Im}[\omega_n](\tau - v) - i\mathrm{Re}[\omega_n]v}}$$

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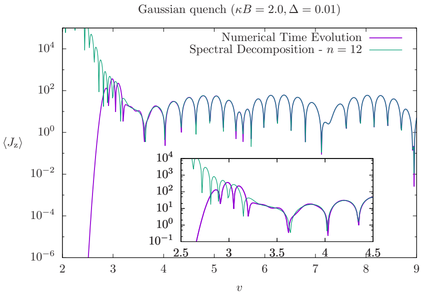
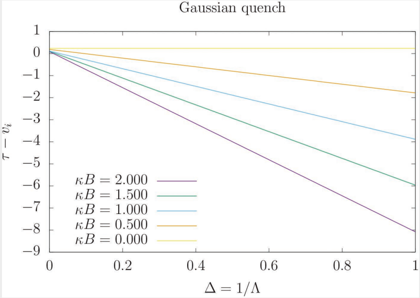
Comparing both methods...

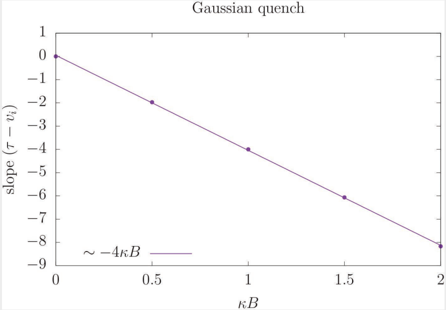
The Laplace analysis fits the explicit time evolution nicely for $v > \tau$



τ behavior

We explore the possibility of considering τ as a well defined notion of "initial time" for linear (or linearized) out of equilibrium systems and compute the dependence of τ on the width of the quench Λ^{-1} and on the anomaly parameter κB





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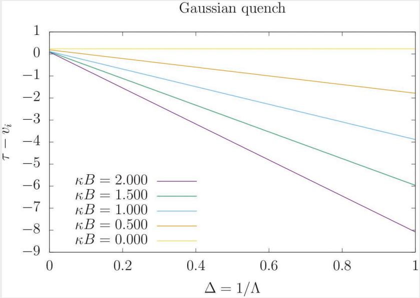

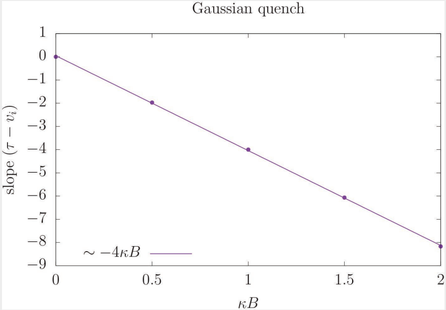

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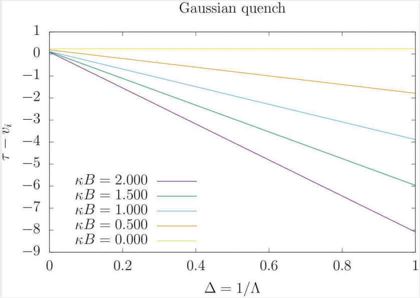

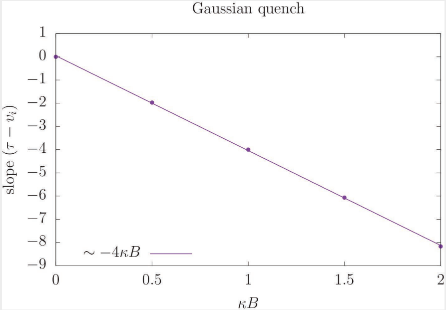

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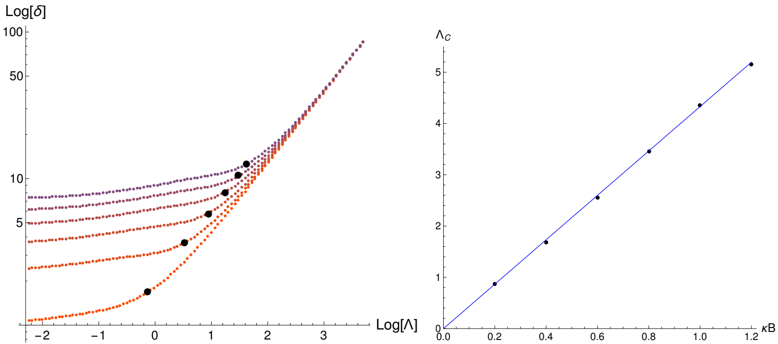
Universal behavior for fast quenches [Buchel et al.]

Define δ as the absolute value of the difference between the first and the second maximum of the current



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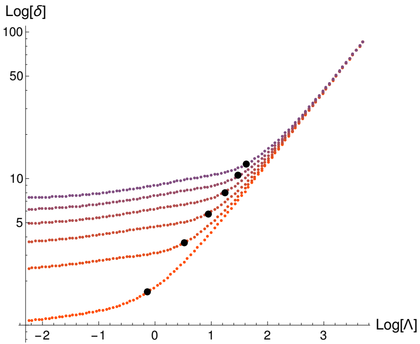

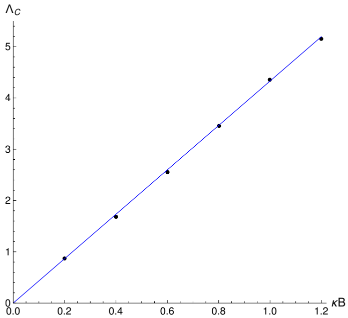

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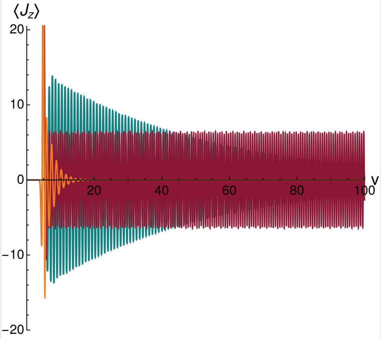
Late time: Suppressed decay

- For late times (far from the quench) one expects an exponential decay given by the lowest QNM



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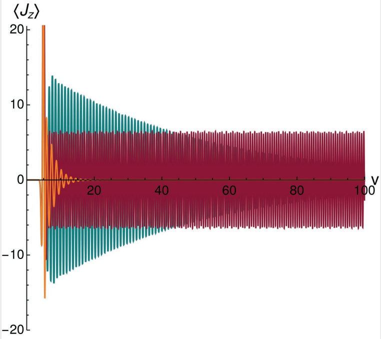

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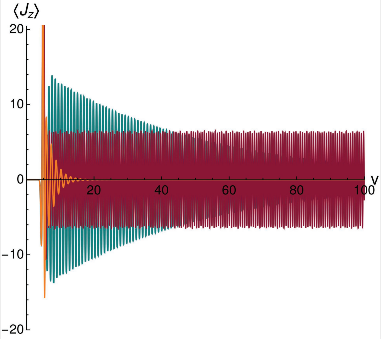

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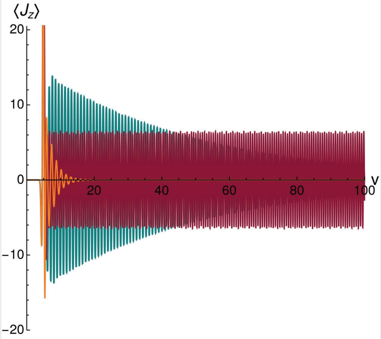

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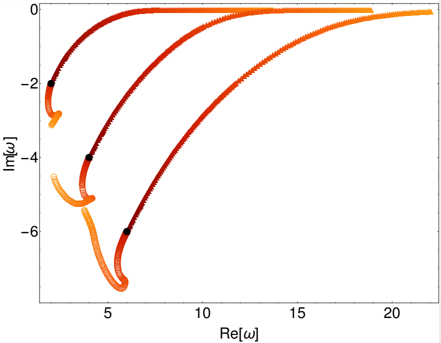

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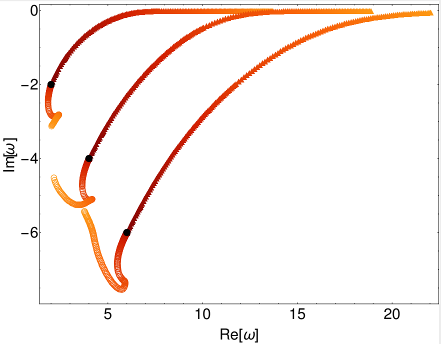

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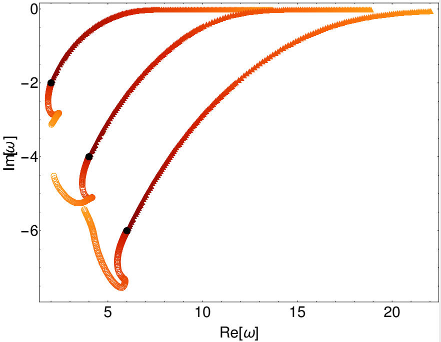

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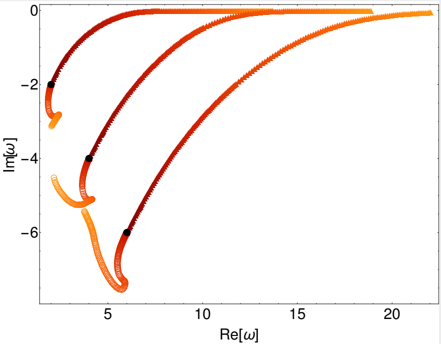

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- Is τ an interesting quantity to characterize initial response?
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Thanks for your attention!!